

Market-Based Approaches for Controlling Space Mission Costs: The Cassini Resource Exchange

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ABSTRACT

Using economic incentives to control costs is a new concept for space missions. The basic tenants of market-based approaches runs counter to typical centralized management techniques often utilized for complex space missions. NASA's Cassini mission to Saturn used a market trading system to assist the Science Instrument Manager in guiding the development of the spacecraft's science payload. This system allowed science instrument teams to trade resources among themselves to best manage their resources (mass, power, data rate, and budget). Thus, Cassini Project management was no longer responsible for adjudicating and reallocating resources that result from instrument development problems. Instrument teams were responsible for directly managing their resources and if they ran into a development problem it was their responsibility to resolve their problem by descope or through the use of a "resource exchange". Under the trading system, instrument cost growth was less than 1% and the total payload mass was under its allocation by 3%. This result is in stark contrast to the 50% -100% increases in theses resources on past missions.

KEY WORDS: Project Management, Instrument Development, Cost Management, Trading

1.0 INTRODUCTION

The general outcome of instrument development for planetary missions has been characterized by significant (50% - 100%) increases in mass, power, data rate and/or cost. One of the main issues confronting the management of complex space science missions is the uncertainty of the resources required to design, develop, test and operate sophisticated spacecraft subsystems and instruments. Typically, management of missions have been highly centralized with all major resource allocation and problem resolution processes occurring by lengthy reviews and management adjudication. Faced with considerable uncertainties, project management regularly holds reserves of critical resources such as power, mass and funds (see Ruskin (1982) for further explanations). The reserves serve as an insurance pool against which claims can be made by instruments and spacecraft subsystems.

The holding of reserves for insurance purposes is not without costs. First, resources must be expended to monitor, review and mediate claims on reserves. Second, the existence of an insurance pool can have unintended affects that may cause resources to be used in an inefficient manner. This type of consequence has been characterized in the economics and insurance literature as moral hazard (see Arrow (1963) and (1989) for more details on this phenomenon). Moral hazard arises when the insurer cannot observe the behavior that produced the "bad" outcome. This is why insurance premiums take into account the incentives the insured has in investing in risk reducing activities. Thus, insurance companies often use copayments, and premium reductions for low risk groups (e.g. nonsmokers). If instrument development events were truly random and were not related to the designs selected by the instrument teams or their management skills/effort, then holding insurance would make sense. However, in the course of instrument development on space missions there seems to be universally bad luck. That is, almost all instruments encounter difficulties that require them to request access to the reserve pool of resources. It is an unheard of event to have an instrument return resources to the project because it had encountered good luck in its development. For example, Polk (1994) has shown that for instrument development, the incentives are such that reserves will be considered as common property and thus an "over-grazing" of those funds will occur. For example, Principal Investigators (PI) may face a choice between a conservative design with a well-established capability and a demonstrated cost or an ambitious design with an increased capability and a "less precise" cost. A margin policy makes the ambitious design more desirable, since spacecraft resources are available if the design encounters technical problems. This moral hazard can lead investigations to an untenable design that could result in an instrument descope or possibly de-selection from the science payload.

One clear indication that moral hazard is present in instrument development is the absence of insurance companies willing to underwrite instrument development risks since it is costly or impossible to determine the source of poor performance. It is clear that the lure of insurance would affect the decisions made by the instrument developers which are contrary to the interests of the insurance company. Furthermore, an internal insurance market in which voluntary premiums are paid by instruments willing to fund a pool will likely result in only the highest risk participants signing up. This phenomena is known as adverse selection in the insurance literature (see Akerlof (1970) and Laffont (1989) for a discussion of this issue).

This paper investigates the use of market-based approaches to allocate and manage science instrument development resources. In particular, we review and analyze the management process used on NASA's Cassini mission to Saturn that allocated the entire science instrument resource envelope among the science teams and allowed trading to occur. Cassini is an international mission to explore the planet Saturn that was launched On October 15, 1997 and will arrive at the ringed planet on July 1, 2004. Upon arrival, Cassini will release the European Space Agency's Huygens Probe into Titan (Saturn's largest moon), followed by more than 60 orbits about the ringed planet. This orbiting observatory will carry twelve science investigations, while the probe carries another six. One unique management philosophy, adopted by the Cassini Project, is that no one investigation was deemed essential. This can be interpreted to mean that the project would not necessarily allocate additional resources to save an investigation if developmental issues arose. In addition to the trading system used during instrument development, we discuss the market-based alternatives being considered to allocated resources to conduct science observations during Cassini operations.

2.0 A BRIEF HISTORY OF INSTRUMENT RESOURCE GROWTH

Instruments are selected for a mission based on proposals submitted by PIs responding to a Request For Proposals sent out by NASA. Once selected, the PIs sign a Letter of Agreement (LOA) which specifies the resources (e.g., mass, power, budget, etc.) that they will be allocated to build their instrument. In general, these letters are goals for both the investigator to stay within their specified resource envelope, and the project to not sequester resources. These goals are rarely met for deep space missions. Changes are commonplace and resource requirements tend to grow while the project imposes unfunded interface changes on the science payload. This fact has led to the holding of reserves. That is, the Science Instrument Manager (SIM) does not allocate the entire science payload budget to the investigators. He maintains a reserve, which is managed and distributed by the SIM, to resolve instrument difficulties. This account is different from the financial reserves held by the Spacecraft Systems Office (SSO). The SSO, which builds the spacecraft bus, maintains its own reserve of resources. These resources are used to solve spacecraft issues as well as those associated with instrument development. Thus, instrument development issues which require an increase in budget come from the SIM, while those that require spacecraft mass, power, data volume, etc. come from the SSO.

Past missions treated the science payload as one subsystem. Instrument growth in one resource could be compensated by a decreased usage of a particular resource by another investigation. This margin approach leads to the situation referred to in the introduction as "moral hazard."

When the PI turns to the SIM for additional resources many questions arise that can affect the quality of the mission's science return. In particular, the following issues arise:

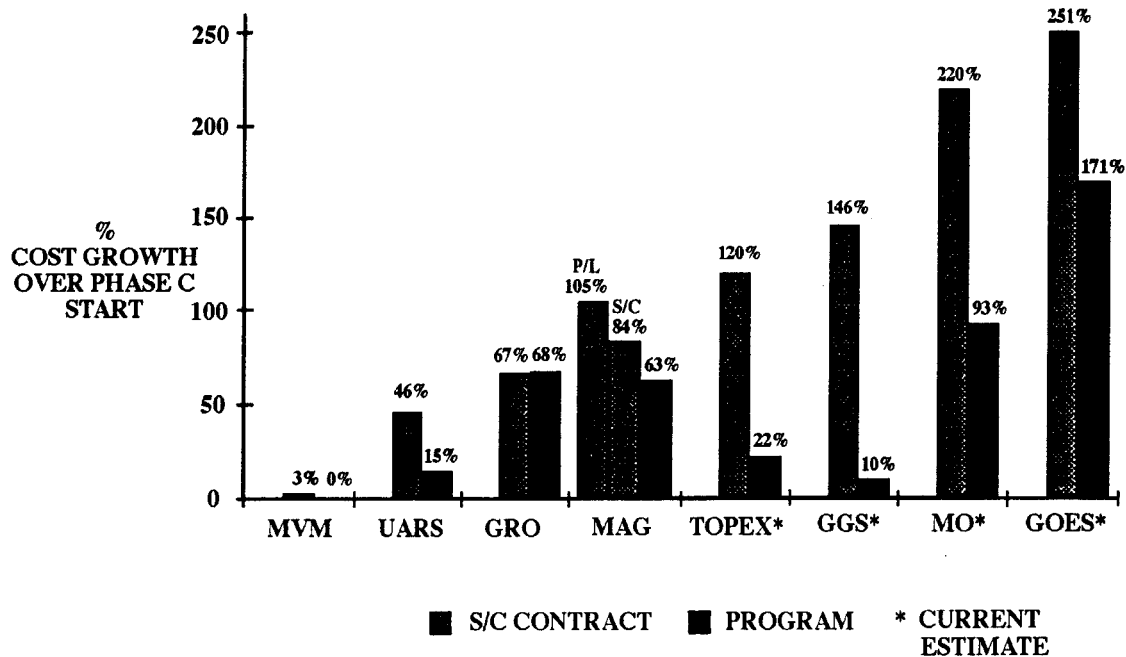
1. Are there enough resources available to solve the problem?
2. Is the request a result of an increase in instrument scope or just a technical issue associated with the desired instrument?
3. Will other investigations develop problems that will require the resources used to solve the current instrument problem?
4. If there are future instrument problems, will they be more important to solve than the current instrument problem?

Obviously, many of these questions cannot be answered apriori. However, what is known is that instrument teams care most about the quality of their own instrument, and that the quality of any instrument increases with the increase of resources assigned to it.

2.1 Cost Growth of Past Planetary Missions

What has been the outcome of this form of management? Figure 1 shows the percent cost growth of past spacecraft contracts and their associated programs (data for the figure were derived from Science Systems Contract Study, Final Report, CSP Associates, Inc., Vol. 1, p. 43. 1993). Instrument cost growths are included in the spacecraft contract cost. It is not possible to extract instrument cost growth from their associated program cost, in retrospect, due to the difficulty of determining which costs come from instrument development issues and those associated with changes to the mission (e.g., launch vehicle change, launch date slip, trajectory change, etc.). Fortunately, this analysis was performed for Mars Observer and will be compared in detail to the Cassini mission.

Figure 1: Percent Cost Growth for Past Space Missions



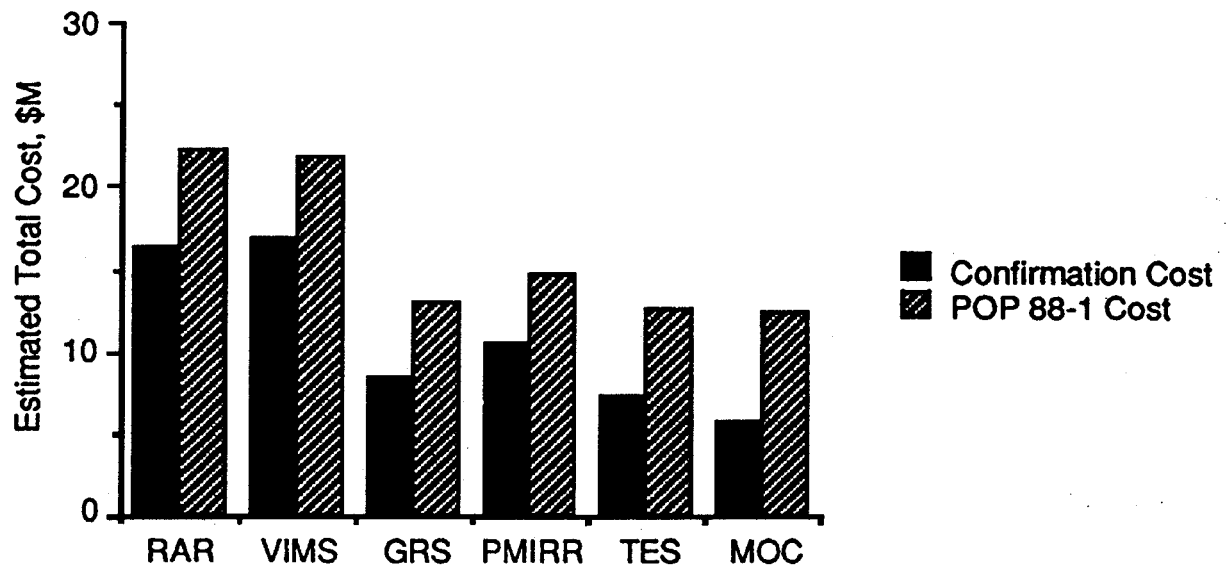
MVM = Mariner Venus/Mercury (1973)
 UARS = Upper Atmosphere Research Satellite (1991)
 GRO = Compton Gamma Ray Observatory (1990)
 MAG = Magellan (1989)
 TOPEX = Topography Experiment/Poseidon (1992)
 GGS = Global Geospace Science (Wind and Polar)
 MO = Mars Observer (1992)
 GOES = Geosynchronous Operational Environmental Satellite

As the figure clearly shows, cost growth is always positive and a common factor in the development of any spacecraft. What is not clear, is how to mitigate the cost for additional resources in the fixed-price environment for building today's spacecraft. In other words, future missions will not have additional resources to accommodate growth so incentives must be developed to curb requests.

2.2 Mars Observer Instrument Cost and Mass Growth

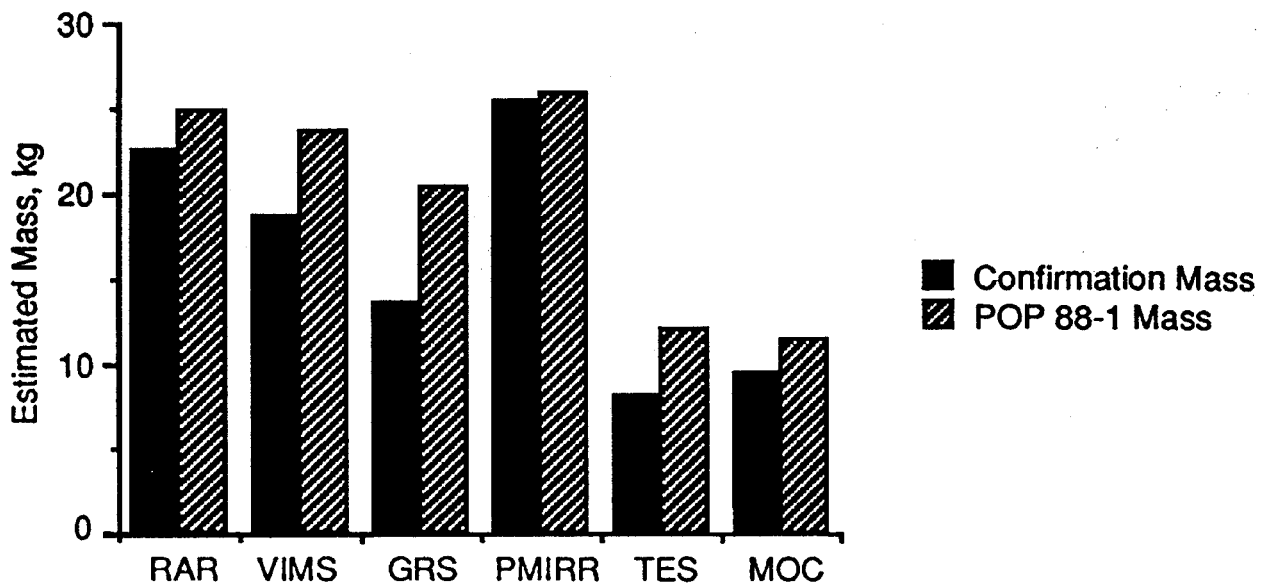
The potentially hazardous effect of instrument cost and mass growth can result in instrument descopes in capability or de-selection from the science payload. In the case of Mars Observer (see Polk (1990) for a complete history), the instrument cost and mass growths (see Figures 2 & 3) resulted in the descope of the RADAR Altimeter & Radiometer (RAR) for the simpler Mars Observer Laser Altimeter (MOLA), and the de-selection of the Visual & Infrared Mapping Spectrometer (VIMS). Radio Science (RS) and the Magnetometer (MAG) instruments were not included in these figures as most of RS's components were part of the spacecraft's telecommunications subsystem; and MAG was the only "off-the-shelf" instrument which, by definition, experienced very little cost growth.

Figure 2: Mars Observer's Instrument Cost Growth



Confirmation = Confirmation of Selected Investigations (1986)
 POP = Program Operating Plan (Year-Rev)

Figure 3: Mars Observer's Instrument Mass Growth



Confirmation = Confirmation of Selected Investigations (1986)
 POP = Program Operating Plan (Year-Rev)

3.0 A NEW APPROACH: THE CASSINI RESOURCE EXCHANGE

In the fall of 1989, NASA released an Announcement of Opportunity for investigators to participate on a comet rendezvous & asteroid flyby and/or Saturn orbiter mission. Formally known as CRAF/Cassini, these missions relied on a common spacecraft bus to reduce the overall cost of both missions. Unfortunately, budget realities caused the cancellation of CRAF early in 1992. The mere act of removing CRAF from the budget increased the cost of Cassini due to the loss of redundancy with the comet orbiter. As such, the Cassini Project had to develop new approaches for managing resources. The approach adopted by the Cassini Science Office was defined in their management plan.

The Cassini Science Management Plan allowed the instrument teams to trade resources allocated to them (mass, power, data rate and funding) in order to resolve resource issues. Specifically, the SIM would not hold reserves for instrument development difficulties, instead all reserves were allocated to the instrument teams. The instrument teams then used their allocated resources to develop their instrument. The process of initial resource allocations occurred when the project issued Letters of Agreement (LOA) to each instrument PI that contained their allocation of resources. If the PI signed the LOA, they accepted the agreement and the allocation. LOAs for the Cassini investigators were signed in September of 1992.

During the course of development, if an instrument could not meet their LOA, they would become candidates for descopes or cancellation. In turn, if a spacecraft change adversely impacted an instrument, the investigation would be compensated by the project (see Wessen and Porter (1997) for more details of the Cassini Science Management Plan).

In order to facilitate trades of this many interrelated resources, an organized exchange was designed and implemented. This exchange allowed instrument teams to submit bids (offers to exchange one set of resource amounts for another set of resource amounts) that all participants can view and counter with other offers, or accept the stated bid. Two interesting features of this exchange that cannot be found on any other organized exchange^a are:

1. Package bids: These are orders that allow participants to tie demands together. Specifically, portfolios or *packages* of resources can be offered. For example, if an instrument team requires a minimum amount of watts in several operating modes, a bid of 1 watt in mode A and 1 watt in mode B and 1 watt in mode C in exchange for \$12K in FY95 and \$13K in FY96 funds would be possible. These bids allow for all or nothing and partial fulfillment of bids as stated by the participant.
2. Smart system to execute chains: Given the variety of resources and small number of participants, bilateral trading may not suffice. Specifically, several participants may be needed to complete a trade. This phenomena is referred to as "a lack of coincidence of wants." When one participant wants power for mass and another wants mass for funding, they would need another participant to complete the *chain* who would be willing to trade funding for power. This system will find such combinations if they exist.

^a Two notable exceptions are the portfolio trading systems run by NetExchange (see the website <http://www.nex.com> for information) and POSIT (see the website <http://www.itg.com/>).

Since no such system has been used before, the project allowed for pre-testing of the system using experimental methods in economics (see Ledyard et al. (1994) for details of this method). The experiments, using support from the Science Office, were designed to see if instruments could find proper trades, and if the SIM could determine if such trades were feasible (i.e., did not contaminate observations of other instruments or disrupt spacecraft mass properties, etc.). The tests revealed that the system and participants found all possible improving trades (including chains) and executed trades in a timely manner. This part of the process was similar to testbedding functions found in the physical sciences (see Plott (1994) for an introduction to this methodology).

3.1 Cassini Trading History

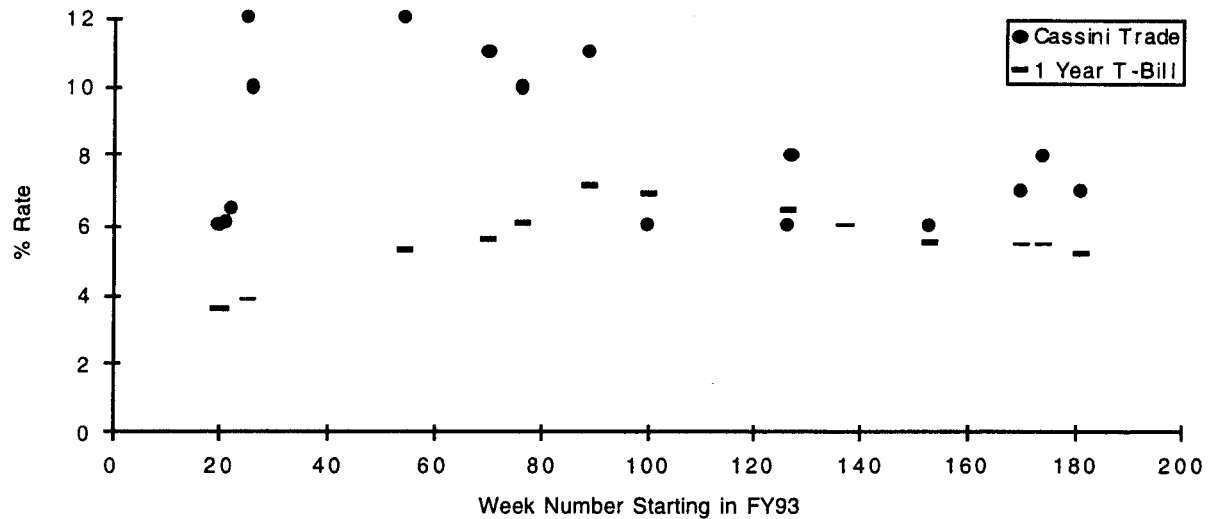
The Cassini Resource Exchange is a computerized, multi-dimensional barter system that resides on the Internet. As a point of history, it was the first “real” trading system that used the Internet as the communication network. Although “IDEA Futures” was in existence prior to the Cassini Exchange, it did not trade in real resources, only “play” money (see Hanson (1995)). The Cassini Resource Exchange design has been modified, and is now being used to trade Emission Credits in Southern California’s RECLAIM program (see the website <http://www.nex.com>).

While the Cassini Resource Exchange is computerized, it has few participants and low volume; and participants rarely activated the system from their computers. Instead, participants communicated by e-mail or phone calls to the market coordinator who entered bids and trade information into the system and relayed that information via e-mail to the participants.^b

During the early history of the trading system (late 1993 to early 1995), bidding and trading were brisk. Results from the system show that of the 29 successful trades, all but two involved money and mass. Those trades involving current fiscal year (FY) funds for future FY funds, we call “money-market trades.” In Figure 4, we show the activity of money-market trades from the beginning of FY93 to the present. The figure shows the implied interest rate between trades of current year funding for future year funding. For example, a trade of \$200K at the beginning of the fiscal year, in return for \$212K in the next fiscal year, would be seen as a 6% rate on the graph. In all, there were 16 contracts, with over 4 million dollars in funds traded in the money market at an average rate of 8.475%. We have also charted the 1-year Treasury Bill rate during this time period in the figure.

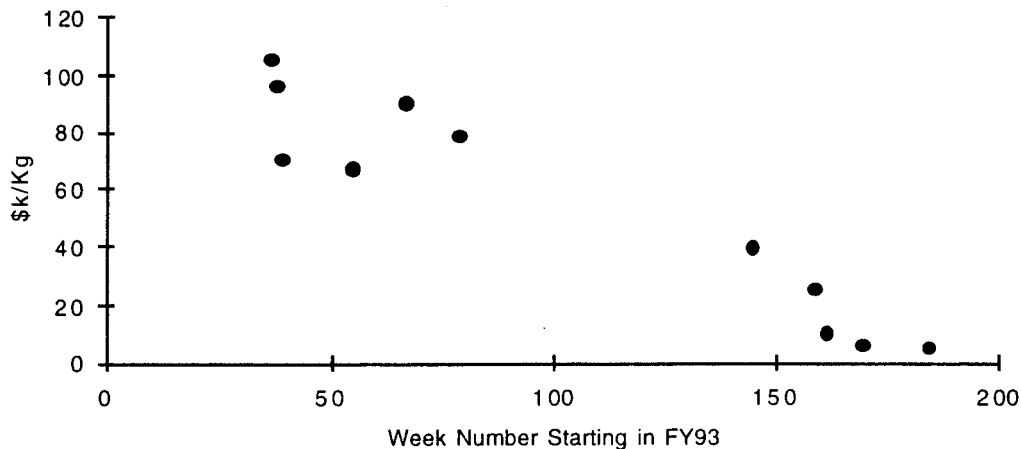
^b The market coordinator was essentially a graduate student at Caltech who, on occasion, checked the system, entered bids and sent e-mail to participants describing the current bids.

Figure 4: Money Market Activity



In the mass market, current and future year funds were traded in return for kilograms of mass. Figure 5 shows the trades that occurred in the mass market. The trades are listed in \$k per kilogram. In this figure, we see the most dramatic price changes with mass price falling from a high of \$105K in the early part of the project to a low of \$5K per kilogram near instrument completion. The market turned out to have an abundance of mass. The abundance of mass seems to have stemmed from two major factors. First, the instruments did an excellent job of managing their mass allocations. Second, the spacecraft also did a great job in managing its mass, so much so that it gave each instrument a 1.07 kg mass "gift" during development. This has not been the case in the history of flight projects, with mass being a very dear commodity near the project completion. Indeed, when the system was first proposed, several participants thought that mass prices would be very high with no one being able to afford mass if they ran into difficulties. This has not been the case. There have been 11 contracts with over 12 kilograms exchanged.

Figure 5: Mass Market Activity



Recall that power (peak power in Watts) and data rate were designated by operational mode. That is, there are 6 spacecraft operational modes that identify when an instrument will be on taking data. If an instrument required more power, it needed to obtain power in all the operational modes in which increased power was required. This is a much more complex commodity, and broaches the operational portion of the mission. As such, not much activity was registered for these commodities. Very few bids were tendered for power and only two trades occurred. These trades had 2 watts of power traded across five operational modes at a price of approximately \$20K/watt.

3.2 A Cassini Mass Auction

One of the more unusual trades involved the Radio & Plasma Wave Subsystem (RPWS). In this case, the RPWS electric antennas had to be moved from the end of the Magnetometer Boom to the spacecraft basebody for spacecraft stability reasons. Moving the antennas to the basebody was a new spacecraft requirement, but would cost the PI either 14 kg of mass plus \$326 k for the thicker 1-1/8" diameter antennas, or zero mass plus \$626 k for the new 3/4" antennas (see Fawcett (1996) for more details).

The Cassini Spacecraft Office had mass but no dollars to alleviate the problem. The resolution was to hold a mass auction to raise the necessary funds. Since RPWS desired the thicker antennas, the plan was to have the Spacecraft Office give RPWS 14 kg to account for the mass of the thicker antennas. The Spacecraft Office then held a mass auction to raise the required \$326 k. The auction accepted "blind" bids from the PIs. That is, each PI who desired additional mass submitted a bid for X kg at \$Y/kg. The bids were opened by the Project and arranged in descending order according to the highest \$Y/kg bid. Mass was sold until the required funds were raised.

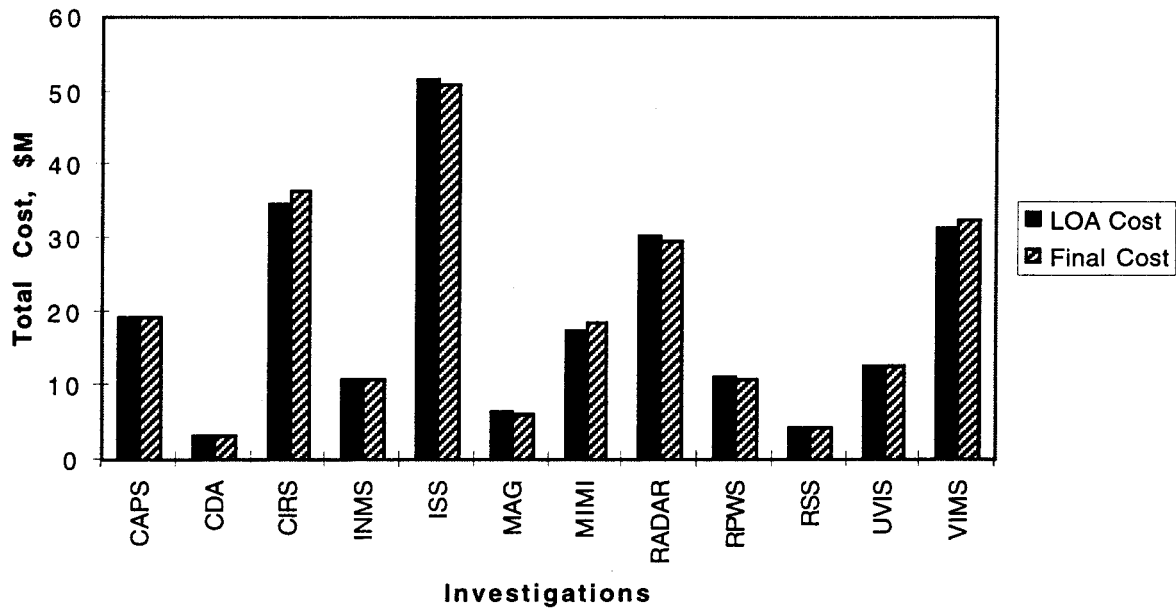
Results from the auction revealed that 10 bids requesting 20.4 kg were submitted. The average bid price per kilogram of mass was \$46 k. The Project sold 4.634 kg at an average price of \$70.35 k/kg. The auction was viewed as "quite successful" and was only possible because the PIs were in control of their resources.

3.3 Cassini Instrument Cost and Mass Growth

Figures 6 & 7 show the Cassini instrument cost and mass growth for the four-year period between the signing of the LOA in 1992 and the Cassini Budget Report, dated 1996 December 12 for funding levels; and Cassini Mass Report, dated 1997 September for mass.

Instrument cost growth across all twelve Cassini Orbiter science instruments averaged 0.9% (see figure 6).

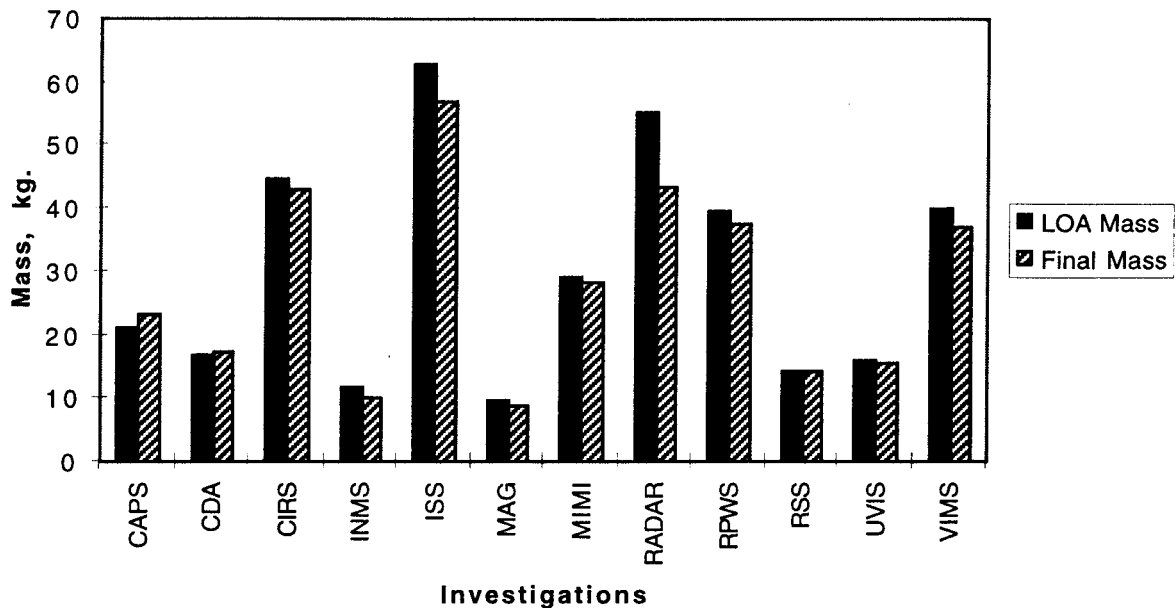
Figure 6: Cassini's Instrument Cost Growth



CAPS - Cassini Plasma Spectrometer
 CDA - Cosmic Dust Analyzer
 CIRS - Composite Infrared Spectrometer
 INMS - Ion and Neutral Mass Spectrometer
 ISS - Imaging Science Subsystem
 MAG - Dual Technique Magnetometer
 MIMI - Magnetospheric Imaging Instrument
 RADAR - Cassini Radar
 RPWS - Radio and Plasma Wave Subsystem
 RSS - Radio Science Subsystem
 UVIS - Ultraviolet Imaging Spectrograph
 VIMS - Visual and Infrared Mapping Spectrometer

Figure 7 shows an average instrument mass growth of -3.2%. The negative value indicates that the investigators did an excellent job controlling their growth.

Figure 7: Cassini's Instrument Mass Growth



4.0 WHAT WAS LEARNED?

By all indications, the Cassini Science Management Plan had a strong influence on the resource management used by science instrument teams. Most of the trading that occurred seem to be of two types. First, many of the trades had instruments loaning current year funds for next year funds. These trades were facilitated by the fact that carrying funds from one year to the next could get interest only if it were traded. Those instruments that had funding profiles that were not in line with their development plan benefited from this system since they were able to readily make trades. The second most common type of transaction was mass for money. Early in the development phase some instruments bought mass because they knew that their instrument was going to grow or at least wanted to self insure against late mass growth. The relatively high prices paid for mass early in the development phase seems to have signaled instruments to better manage their mass. As a result, most instruments at the end of the development phase had excess mass available and thus prices fell dramatically. The "left-over" mass was a welcomed relief for CAPS, who had some very late development issues and thus needed help after most instruments were delivered.

The exchange system did have its problems. As the system was designed, there was no connection between the Development and the Operational phase of the mission. If an instrument had a problem late in Development, and the remaining instruments were already built, there were no incentives for other investigators to help the struggling investigation. The LOA did state that residual resources would revert back to the Project after Flight Model delivery, but in most cases this was too late to help the unfortunate investigation. It is recommended that if future missions use this system, a mechanism be put in place that straddles the Development and Operational phases of the mission.

The exchange system also did not include development schedule (i.e., time) as one of the dimensions to be traded. As a result, almost all instrument deliveries were late. Though this is a common occurrence among planetary missions, it nevertheless increases the risk of being able to return high quality data from the investigations.

Even though a computerized trading system was available to participants virtually all trades were "brokered" with emails informing participants of offers and bids that were on the system. With the universal acceptance of the World-Wide Web and the familiarity with browsers, it seems that the use of computerized negotiations will be used more in the future.

5.0 EXTENSION OF THE SYSTEM TO SCIENCE PLANNING

Given the results of the Resource Exchange, the Project is now considering an extension of the market-based system to science planning. Such a system would involve three dimensions: observation duration, observation priority, and data volume. These commodities would be traded by the science community to produce a timeline of events spanning the entire 4-year Saturnian tour.

Previously, missions typically used a "committee-driven" process to do their science planning. PIs would submit observation requests with their associated resources (e.g. observation duration, number of computer command words, data volume, etc.) and then a team of Integrators would combine the requests into a single timeline. These Integrators faced the daunting task of generating a timeline that was free of observations that demanded the same time (on the timeline) while taking only the highest priority observations. Typically, timelines were oversubscribed by 100% - 300%. Integrators also had to be "fair" to all of PIs. As such, Integrators would try to select one high priority observation from each investigation prior to selecting a second high priority observation.

Once the entire timeline was completely subscribed ("conflict-free"), it would be presented to a committee composed of PIs for their approval. Needless to say, there were always PIs that were pleased with the results and those that were not. All concerns raised by the PIs were given back to the Integrators to "solve". The resulting timeline was once again presented to the PIs for their comments, and once again given back to the Integrators to rework. Typically there would be three main integrations (e.g., Preliminary, Intermediate, and Final), and numerous smaller meetings to resolve other issues raised by a PI that had "lost the integration wars".

PIs, whose observations had a high science value and did not make it on to the timeline might choose to present their justification, for inclusion on to the timeline, to members of the Science Office. With each loss the PI could appeal to a higher science authority. Critical science issues invariably worked their way up to the level of the Project Scientist. The final decision pertaining to which observation should be included on the timeline rested with the Project Scientist. As such, science planning by a "committee-driven" process was usually labor-intensive and time-consuming.

In a market-based approach, investigators are given an initial amount of some resource. These resources could be intervals of time on the timeline, computer command words, data volume, and/or priority points (i.e., chits). Chits are a unit of exchange that can be used to express the

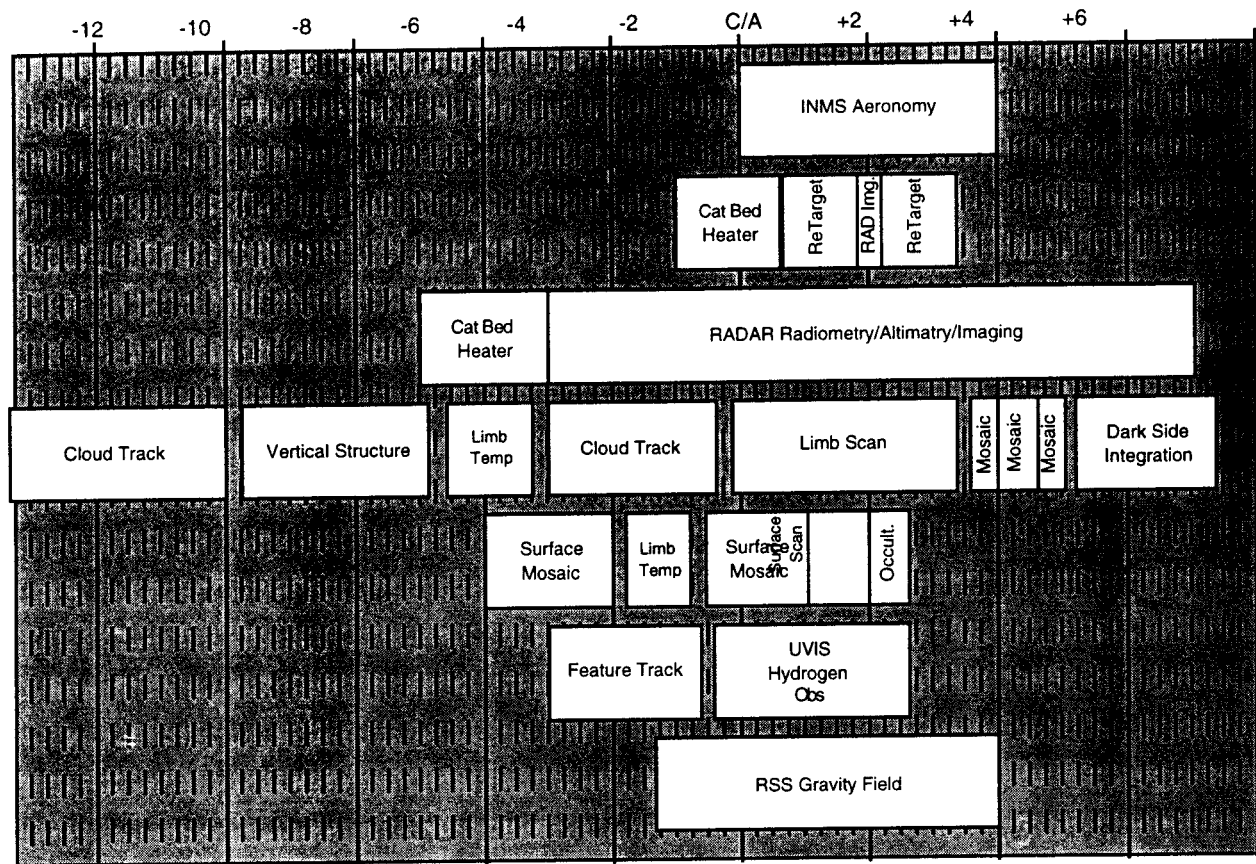
importance of one observation over another. That is, the more chits associated with a given observation, the more important the observation.

It is realized that the results of a market-based system are sensitive to its initial allocations. However, it is much easier to handle a difficult problem (i.e., the initial allocation) earlier in a process rather than waiting until it ends (i.e., solving observation conflicts). In addition, multiple allocation of these resources may be used to reduce the system's sensitivity to the initial allocation.

The Cassini Project will also evaluate which of two resources should be initially allocated. The first involves dividing the 4-year Saturn tour into many smaller segments. Each segment represents a period of time when particular geometric constraint can be met for a particular class of observation. The full set of segments will then be divided into four disciplines: Atmospheres, Magnetosphere & Plasma Science (MAPS), Rings, and Surfaces based on the segment's science objective. Discipline Working Groups will then take their allotment of segments and subdivide into discrete observations. It will be the Discipline Working Groups responsibility to decide which observation(s) will be requested and to ensure that each segment is "conflict-free".

As an example of segments and observations, figure 6 shows one Titan segment. This segment starts at -13 hours prior to Titan Closest Approach (C/A) and continues till +6 hours past the event. Each rectangle represents a unique activity/observation and, for any given time, must be performed by itself. Notice that at the time of C/A, seven different activities have been identified. Deciding which activity to select, based on science return, is a very time consuming undertaking and would have to be repeated for each Titan swingby. In Cassini's case, this would have to be performed over forty times.

Figure 6. Titan timeline from -13 hrs to +6 hrs around Titan closest approach



Once the segments are divided into activities/observations, trades between Discipline Working Groups can be made. This approach still requires that the tour be divided into segments and that the Discipline Working Groups somehow reach consensus pertaining to allocating time to the myriad of science opportunities available in one finite segment. However, this approach does remove the non-trivial task of allocating chits to the different disciplines.

After a conflict-free timeline is produced, observations are assigned to the investigation that will perform the experiment. Once this is done, the "after-market" begins. This process allows for trades between PIs of any of the resources "owned" by their investigation. It is envisioned that trades between observation time, computer command words, and data volume will be made to fine-tune the results from the segment/observation trading phase.

The second approach for allocating initial resources involves allocating chits to the different disciplines. These chits are used by each discipline to express the relative importance of one observation over another. This is done by electronically "bidding" a number of chits to each observation. Thus, if two observations require the same execution time, the one that bid the larger number of chits "wins" those timeline resources. In this manner, individuals internal to the discipline or across disciplines can assess the relative importance of the particular observation and how many resources (i.e., chits) would be required to displace it. This approach can also be

implemented in a number of different manners. Chits can be distributed by the Cassini Science Office to the Disciplines, who in turn allocate the chits to investigators in their discipline; or the chits may be allocated directly to the PIs. Our plans are to run experiments for both cases in order to understand the strengths and weaknesses of the two approaches.

It is realized that a market-based approach has a number of very useful attributes over one that is "committee-driven". First, observation durations will be closer to the minimum amount of time necessary rather than the maximum amount of time desired to accomplish a given measurement. This results from the fact that the larger the requested duration, the greater the odds that the request will conflict with another observation resulting in a "bidding war". This should be incentive enough to minimize the length of their observation requests. Next, a market-based approach promotes synergistic observations. If investigator A did not have the resources to out bid investigator B, investigator C might contribute to observation A to obtain quality observation time for less than if investigator C bided for the time alone.

In addition, the timeline is always "conflict-free". That is there is never an over-subscription of resources. Investigators either "own" the resource or they don't. Finally, a market-based system is compatible with the distributed operations concept which is being used by the Cassini Project for mission operations. Currently, commands for all PI instruments originate at their home institution. Performing science planning remotely with the use of the Internet is consistent with distributed operation responsibilities already accepted by the PIs.

Once the timeline is developed, an "after-market" phase begins. Here again, trades between observation time, computer command words, and data volume will be made to fine-tune the results from the first phase. Once completed, the timeline will be compared to those generated from alternate approaches. Differences will be identified, evaluated and a single approach will be proposed which minimizes the effort required to generate the timeline and still produces the greatest science return.

6.0 CONCLUSIONS

Past approaches for allocating resources to PIs have always resided in the Project Office. Though the approach has continued to improve with each mission, the challenges of the system remained. Projects only mechanism for reducing the demand for additional spacecraft resources was the early recognition of instrument development issues. The Science Instrument Manager still had to allocate a limited amount of resources to the PIs as development problems arose. But this mechanism provided the wrong incentive to the instrument developers. It rewarded instrument teams for developing instrument problems early. This approach also forced the Science Instrument Manager to make educated guesses about the source of the instrument problems. There were no metrics to help determine if the problem resulted from an increase in instrument scope, an unanticipated technical challenge, or simply an oversight in the initial allocation of resources. When the Science Instrument Manager finally exhausted his resources, instruments that encountered additional difficulties were either descope or de-selected from the mission.

The continual demand for additional resources during instrument development shows that a margin policy does little to slow the demand for additional resources and that it in turn will be used until depletion. To stem this demand, an alternate mechanism must be used which allows for the re-allocation of currently available resources, without requiring constant replenishment from the

project. This mechanism, to be used efficiently, must also be used by the individuals that have the largest vested interest in the success of each instrument, namely the Principal Investigators themselves.

The Cassini Resource Exchange removed the responsibility of solving instrument development issues from the Science Instrument Manager, and placed it back on the PIs. As a result of the Resource Exchange system, 29 trades were successfully made, \$4 million were traded to resolve funding profile issues, 12 kg were traded among the investigators, and cost & mass growth were all but non-existent. Cassini PIs also returned resources back to the project. Research indicates that few missions, if any, had resources available after instrument development.

Applying a market-based approach to Cassini's science planning activities should also produce savings. That is, the timeline should be produced in less time and have the same high quality of science as compared to a "committee-driven process. Applied to science planning, the timeline resources will never be oversubscribed. Observation resource requirements will be kept from expanding just as the Cassini Resource Exchange successfully kept instrument requirements from expanding. The approach has the added benefit that it may be performed from remote locations as the system resides on the Internet.

As the market-based approach is applied to Cassini science planning, a parallel effort is underway to evaluate the same type of approach for LightSAR. LightSAR is a commercially built and operated RADAR spacecraft servicing both the commercial and academic sectors. An Internet, market-based system for planning RADAR observations is very similar to Cassini's science planning approach and should realize the same results.

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